

# Recognizing the component tones of a major chord

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Listeners judged whether a target tone was contained within a previously or subsequently presented major chord, and targets consisted of either the root, third, fifth, or tritone of the scale based on the root of the chords. Chord position influenced the relative recognition of targets, but listeners exhibited greater recognition of the fifth regardless of chord position (root, first inversion, second inversion). The data were not consistent with notions of root tracking or melody tracking. The data were broadly consistent with the notion that different chord positions may be harmonically equivalent (i.e., that listeners may recognize components of a chord regardless of chord position), with notions of analytic set and the importance of an instantiation of musical context for chord processing, and with the importance of the fifth in harmonic progression.

Most Western tonal music contains multiple parts or voices that sound simultaneously, and the prescriptions of harmony and voice-leading dictate which combinations of pitches are acceptable and which are not acceptable. In homophonic music, a single voice is designated as the melody, and the remaining voices provide harmonic or rhythmic accompaniment. The voice perceived as melody may be heard as a figure against the background of the other voices (e.g., as a separate stream [Bregman, 1990; Dowling, 1973]), and performers may emphasize the melodic voice more than other voices (e.g., the melodic voice is louder and enters earlier [Palmer, 1989; Rasch, 1979]). The ability of a listener to hear one voice as melody and relegate the remaining voices to background or accompaniment suggests that not all voices are recognized equally well or as equally important.

In the Western tonal system, simultaneously presented voices form chords, and the most stable and ubiquitous chord is the major chord. A major chord may be constructed by choosing a tone to function as the base or root and then adding tones a major third and fifth above that root (Kostka & Payne, 1995; see also the Appendix). When the root is the lowest pitch, the chord is said to be in root position. When the third is the lowest pitch, the chord is said to be in first inversion; when

the fifth is the lowest pitch, the chord is said to be in second inversion. These different chord positions have been suggested to fulfill equivalent harmonic roles (Rameau, 1750/1971; Piston, 1978), but they are perceptually distinct. Normally, the rich context of homophonic, polyphonic, or contrapuntal compositions provides ample cues about the relative importance of each voice in a chord, but to examine more closely whether there are biases or preferences in the processing of the individual voices of a chord, it is also desirable to examine how well listeners recognize and attend to each voice of a single chord presented in isolation.

The prominence of the soprano line (i.e., the higher voice) in contemporary theories of voice leading and arrangement (Aldwell & Schacter, 1978; Palmer & van de Sande, 1993; Williams, 1992) suggests that tones with higher auditory frequencies in a chord should be more salient and therefore more easily recognized than tones with intermediate or lower auditory frequencies. Listeners are more accurate at detecting entrances for higher-frequency voices than for intermediate-frequency voices (Huron, 1989) and are also more accurate at detecting a pitch change in multivoice music when the pitch change occurs in the highest-frequency voice (Palmer & Holleran, 1994). When one of the component tones of a chord is replaced with white noise, listeners are more accurate at detecting the change when it occurs in the highest-frequency component (DeWitt & Samuel, 1990). When musically experienced listeners rate how similar a separately presented pure tone sounds to a major chord containing that tone, the tonal component with the highest frequency is rated as sounding most similar to the chord (Platt & Racine, 1990). The notion that the highest-frequency voice is the most salient and that listeners treat that voice as figure has been called melody tracking (Farnsworth, 1938).

Even though the highest-frequency voice usually carries the melody, the harmonic context or role of a chord usually is determined by the root of the chord. The harmonic context influences goodness-of-fit ratings (Krumhansl, 1979; Krumhansl & Kessler, 1982) and how well listeners can detect pitch (Jones, Holleran, & Butler, 1991; Palmer & Holleran, 1994; Palmer & van de Sande, 1993) and chord (Bharucha & Krumhansl, 1983) changes. Listeners with a moderate amount of training rate the elements of a chord as fitting better than do other tones with that chord, and the root and the fifth are rated higher than the third (Thompson & Parncutt, 1997). Also, when listeners adjust a comparison tone to match the perceived pitch of one of the components of a chord, musically inexperienced listeners are influenced by chord position, whereas musically experienced listeners are influenced more by the root of the chord and less by chord position (Platt, Racine, Stark,

& Weiser, 1990). This pattern suggests that musically experienced listeners may interpret the root as more salient, and the prominence of the root in the establishment of musical key suggests that the root should be more salient and therefore more easily recognized. The notion that the root is the most salient and that listeners treat the voice performing the root as figure has been called root tracking (Platt & Racine, 1990).

Previous experiments have focused on the degree to which a given tone was judged to fit a cadence or other context, on how well listeners could detect pitch changes, or on global judgments of how well a tone "matched" a chord. The component of the chord treated as figure presumably would be more easily recognized than would be the other components of the chord, so the experiments reported here adopted a simpler approach in which listeners judged whether a target tone was contained within a previously or subsequently presented major chord. The target corresponded to the root, third, or fifth of the chord or to the tritone of the major scale based on the root of the chord (the root, third, and fifth were present within the chord, and the tritone was not present within the chord). To disentangle effects of pitch height (i.e., the absolute auditory frequency) and effects of the harmonic relationship of the target to the chord (i.e., whether the target corresponded to the root, third, fifth, or tritone), listeners were presented with chords in either root position, first inversion, or second inversion. Measures of the musical background of the listeners were also collected and were used to classify listeners as musically experienced or inexperienced.

## **EXPERIMENT 1**

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In this experiment, listeners judged whether a target tone was contained within a previously (Experiment 1A) or subsequently (Experiment 1B) presented major chord. Chords were presented in root position, first inversion, or second inversion, and targets corresponded to the root, third, or fifth of the chord or to the tritone of the major scale based on the root of the chord. If melody tracking occurs (i.e., if the highest note is more figural or salient), then the highest recognition rate should occur when the target corresponds to the highest note of the chord, and this should occur regardless of chord position. If root tracking occurs (i.e., if the root is more figural or salient), then the highest recognition rate should occur when the target corresponds to the root of the chord, and this should occur regardless of whether the target is the low, middle, or high voice of the chord.

## METHOD

### Participants

Listeners in all experiments were undergraduates at Texas Christian University who participated in return for partial course credit, and musical experience was not used as a criterion for participation. A total of 48 listeners participated in Experiment 1; 24 listeners participated in Experiment 1A, and 24 listeners participated in Experiment 1B.

### Apparatus

Stimuli were synthesized by an Apple Macintosh IIsi microcomputer and presented to listeners via headphones (Radio Shack Nova-35).

### Stimuli

In Experiment 1A, the chords preceded the targets, and in Experiment 1B, the targets preceded the chords. Major chords (consisting of a root, third, and fifth) were presented in either root position, first inversion, or second inversion (see Figure 1, top). Target tones presented on each trial corresponded to the root, third, or fifth of the chord presented on that trial or to the tritone of the major scale based on the root of the chord presented on that trial. Target tones and the constituent tones of each major chord were sine waves, and the use of sine waves minimized potential confounds caused by any differential priming of the root, third, or fifth by harmonics. Six different roots were drawn


Exps. 1A and 1B							
Exps. 2A and 2B							
Exps. 3A and 3B							
	<table border="0"> <tr> <td style="padding: 0 10px;">Root</td> <td style="padding: 0 10px;">First</td> <td style="padding: 0 10px;">Second</td> </tr> <tr> <td style="padding: 0 10px;">Position</td> <td style="padding: 0 10px;">Inversion</td> <td style="padding: 0 10px;">Inversion</td> </tr> </table>	Root	First	Second	Position	Inversion	Inversion
Root	First	Second					
Position	Inversion	Inversion					

Figure 1. Examples of root position, first inversion, and second inversion chords; all examples are drawn from the key of C major, but analogous relationships hold for the other keys

from keys equally spaced around the circle of fifths (C [261.61 Hz], D [293.66 Hz], E [329.63 Hz], F $\sharp$  [369.99 Hz], G $\sharp$  [415.30 Hz], and A $\sharp$  [466.16 Hz]), and each root was presented on one-sixth of the trials. The loudness setting on the microcomputer was adjusted to 3 on a 7-point scale (7 was maximum loudness), and listeners could further adjust the loudness level to achieve maximum comfort and confidence by turning a small dial on the headphones. In Experiments 1A and 1B, each listener received 144 trials—three chord positions (root position, first inversion, second inversion)  $\times$  four targets (root, third, fifth, tritone)  $\times$  six root pitches (C, D, E, F $\sharp$ , G $\sharp$ , A $\sharp$ )  $\times$  two replications—in a different random order.

### Procedure

Listeners were first given a set of 12 practice trials drawn randomly from the experimental trials. The listeners initiated each trial by pressing a designated key. In Experiment 1A, the chord played for 2 s, there was a pause of 100 ms, and then the target played for 2 s; in Experiment 1B, the target played for 2 s, there was a pause of 100 ms, and then the chord played for 2 s. In Experiment 1A, listeners judged whether the pitch of the target was the same as any of the pitches of the immediately preceding chord. In Experiment 1B, listeners judged whether any of the pitches of the chord were the same as the pitch of the immediately preceding target. Listeners then pressed either a key marked “S” (for *same*) or a key marked “D” (for *different*) to indicate their response. After the experimental trials, listeners completed a brief musical background questionnaire in which they reported the number of years they had played a musical instrument within a group, sung individually or in a chorus, taken instrumental lessons, taken vocal lessons, or studied music theory.

## RESULTS

Listeners’ responses in each category of the musical background questionnaire were summed to provide a musical experience score for each listener (e.g., a listener who played an instrument for 10 years in a band and who sang in a choir for 10 years would have a musical experience score of 20), and listeners in Experiments 1A and 1B were classified as either musically experienced or musically inexperienced on the basis of a median split of those scores. The probabilities of a “same” response in Experiments 1A and 1B were then analyzed in separate repeated-measures analyses of variance in which target and chord position were within-subject variables and experience was a between-subject variable.

### EXPERIMENT 1A

Listeners in the inexperienced group reported a mean of 1.00 year (range 0–3 years) of instrumental, voice, and music theory experience, and listeners in the experienced group reported a mean of 8.08 years

(range 3–15 years) of instrumental, voice, and music theory experience. Experienced listeners ( $M = .56$ ) were more likely to respond “same” than were inexperienced listeners ( $M = .49$ ),  $F(1, 22) = 5.06$ ,  $MSE = 0.08$ ,  $p < .04$ , but experience did not interact with any other variables. Target was significant,  $F(3, 66) = 40.08$ ,  $MSE = 0.09$ ,  $p < .001$ , and a post-hoc Newman–Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between the root ( $M = .49$ ), third ( $M = .57$ ), fifth ( $M = .78$ ), and tritone ( $M = .22$ ) were significant except for the root versus third comparison. Target also interacted with chord position,  $F(6, 132) = 3.59$ ,  $MSE = 0.03$ ,  $p < .003$ . As shown in Table 1, the probability of a “same” response to the fifth decreased slightly as the amount of chord inversion increased, whereas the probability of a “same” response to the root, third, or tritone was not as systematically influenced by chord position.

### EXPERIMENT 1B

Listeners in the inexperienced group reported a mean of 1.42 years (range 0–4 years) of instrumental, voice, and music theory experience, and listeners in the experienced group reported a mean of 12.83 years (range 5–24 years) of instrumental, voice, and music theory experience. Experience was not significant, nor did it interact with any other variables. Target was significant,  $F(3, 66) = 142.76$ ,  $MSE = 0.07$ ,  $p < .001$ , and a post-hoc Newman–Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between the root ( $M = .73$ ), third ( $M = .75$ ), fifth ( $M = .93$ ), and tritone ( $M = .10$ ) were significant except for the root versus third comparison. Target also interacted with chord position,  $F(6, 132) = 2.82$ ,  $MSE = 0.02$ ,  $p < .02$ . As shown in Table 1, the probability of a “same”

Table 1. The probability of a “same” response in Experiments 1A and 1B

	Chord position		
	Root position	First inversion	Second inversion
Experiment 1A			
Root	.49	.56	.43
Third	.63	.52	.57
Fifth	.86	.79	.71
Tritone	.23	.22	.27
Experiment 1B			
Root	.79	.75	.64
Third	.72	.77	.77
Fifth	.94	.93	.93
Tritone	.07	.08	.14

response to the root decreased as the amount of chord inversion increased, whereas recognition of the third, fifth, or tritone was not as strongly influenced by chord position.

## DISCUSSION

When listeners judged whether a target tone was contained within a previously or subsequently presented major chord, listeners were more likely to recognize that target if it corresponded to the fifth than if it corresponded to the root or to the third. One possible explanation for this pattern is that the construction of the first and second inversion chords introduced a confound in the number of different pitches used for each component in the chords: Within each key, a single pitch was used for the fifth, whereas two different pitches were used for the root and two different pitches were used for the third. Inspection of the top of Figure 1 reveals that the creation of the first inversion chords and the second inversion chords resulted in the root or third being shifted to higher octaves, but the pitch of the fifth remained unchanged. Consider the following example: for chords based on C, the root chord consisted of  $C_4$  (261.63 Hz),  $E_4$  (329.63 Hz), and  $G_4$  (392.00 Hz), the first inversion consisted of  $E_4$ ,  $G_4$ , and  $C_5$  (523.25 Hz), and the second inversion consisted of  $G_4$ ,  $C_5$ , and  $E_5$  (659.26 Hz). Thus, for the key of C, two different roots ( $C_4$  and  $C_5$ ) and two different thirds ( $E_4$  and  $E_5$ ) were presented, but only one fifth ( $G_4$ ) was presented. Thus, the greater recognition of the fifth may have resulted from only one pitch being used for the fifth, two pitches being used for the root, and two pitches being used for the third. An analogous logic holds for chords based on the other five root pitches that were presented.

## EXPERIMENT 2

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In Experiment 1, listeners exhibited higher rates of recognition for the fifth than for recognition of the root or the third. One possible explanation for this pattern is that across the different positions of a given chord, the single pitch that was presented most often corresponded to the fifth. The increased exposure to a specific pitch could have resulted in greater repetition priming or perceptual fluency for that pitch. To test this notion, the same root position and first inversion chords from Experiment 1 were presented, and the root, third, and fifth of each of the second inversion chords from Experiment 1 were lowered by one octave (see Figure 1, middle). This modification ensured that the pitch of the third did not change across the different chord

positions within a key and that the pitch of the fifth was different in second inversion chords from the pitch of the fifth in root position chords and first inversion chords. If the increased exposure to a specific pitch increased the recognition rate of the fifth in Experiment 1, then in Experiment 2 listeners should be more accurate at detecting the third when that pitch is contained within a previously (Experiment 2A) or subsequently (Experiment 2B) presented major chord.

## **METHOD**

### **Participants**

Forty-eight undergraduates from the same pool used in Experiment 1 participated, and none of the listeners had participated in Experiment 1; 24 listeners participated in Experiment 2A, and 24 listeners participated in Experiment 2B.

### **Apparatus**

The apparatus was the same as in Experiment 1.

### **Stimuli**

The stimuli were the same as in Experiment 1, with the following exception: The frequencies of the root, third, and fifth components of each of the second inversion chords were lowered by one octave. In Experiments 2A and 2B, each listener received 144 trials—three chord positions (root position, first inversion, second inversion)  $\times$  four targets (root, third, fifth, tritone)  $\times$  six root pitches (C, D, E, F $\sharp$ , G $\sharp$ , A $\sharp$ )  $\times$  two replications—in a different random order.

### **Procedure**

The procedure for Experiment 2A was the same as in Experiment 1A, and the procedure for Experiment 2B was the same as in Experiment 1B.

## **RESULTS**

Listeners were divided into musically experienced and musically inexperienced groups on the basis of a median split of scores on the musical background questionnaire. The probabilities of a “same” response in Experiments 2A and 2B were then analyzed in separate repeated-measures analyses of variance in which target and chord position were within-subject variables and experience was a between-subject variable.

### **EXPERIMENT 2A**

Listeners in the inexperienced group reported a mean of 0.58 year (range 0–2 years) of instrumental, voice, and music theory experience, and listeners in the experienced group reported a mean of 13.08 years

(range 3–33 years) of instrumental, voice, and music theory experience. Experience was not significant but did interact with target,  $F(3, 69) = 3.41$ ,  $MSE = 0.05$ ,  $p < .03$ , such that differences between the recognition rates of the root and the third and the recognition rate of the fifth were slightly greater in inexperienced listeners. Target was significant,  $F(3, 69) = 122.81$ ,  $MSE = 0.05$ ,  $p < .001$ , and a post-hoc Newman–Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between the root ( $M = .49$ ), third ( $M = .51$ ), fifth ( $M = .84$ ), and tritone ( $M = .16$ ) were significant except for the root versus third comparison. Target also interacted with chord position,  $F(6, 138) = 3.59$ ,  $MSE = 0.03$ ,  $p < .004$ . As shown in Table 2, chord position had a stronger influence on the recognition of the third and the root than on the recognition of the fifth and the tritone.

**EXPERIMENT 2B**

Listeners in the inexperienced group reported a mean of 1.21 years (range 0–3.5 years) of instrumental, voice, and music theory experience, and listeners in the experienced group reported a mean of 12.08 years (range 4–27 years). Experience was not significant, nor did it interact with any other variables. Target was significant,  $F(3, 69) = 403.71$ ,  $MSE = 0.03$ ,  $p < .001$ , and a post-hoc Newman–Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between the root ( $M = .87$ ), third ( $M = .82$ ), fifth ( $M = .96$ ), and tritone ( $M = .10$ ) were significant except for the root versus third comparison. Target also interacted with chord position,  $F(6, 138) = 3.28$ ,  $MSE = 0.01$ ,  $p < .005$ . As shown in Table 2, chord position had a stronger influence on the recognition of the third than on the recognition of the root, fifth, or tritone.

Table 2. The probability of a “same” response in Experiments 2A and 2B

	Chord position		
	Root position	First inversion	Second inversion
Experiment 2A			
Root	.42	.55	.52
Third	.51	.45	.58
Fifth	.85	.79	.89
Tritone	.15	.22	.13
Experiment 2B			
Root	.88	.88	.86
Third	.85	.74	.87
Fifth	.97	.96	.95
Tritone	.09	.08	.11

## DISCUSSION

The data of Experiment 2 are not consistent with root tracking or melody tracking. Listeners exhibited higher recognition rates when targets corresponded to the fifth than when targets corresponded to the root or third, and this pattern occurred even though the most frequently presented single pitch in each key was the third. The greater recognition of the fifth replicates the pattern observed in Experiment 1, and the presence of this pattern in Experiment 2 suggests that the results of Experiment 1 cannot be attributed to repetition priming of the single pitch in each key used for the fifth. Thus, the high recognition of the fifth in Experiment 1 cannot be attributed to the confound between the number of times a specific auditory frequency was presented and whether that specific auditory frequency corresponded to the root, third, or fifth. Also, when the chord preceded the target, inexperienced listeners exhibited a greater difference between the recognition rates of the root and the third and the recognition rate of the fifth, but the reason for this difference is not clear.

## EXPERIMENT 3

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Although it is possible that the use of two different pitches for the root within each key in Experiments 1 and 2 provided a sufficient activation of key at a level abstract from a single specific frequency, it may be that the use of only one pitch for the root for each key might lead to an even greater activation of key. With a potentially greater activation of key, we might expect the root to be more easily recognized than the fifth. The idea that a greater repetition of the root pitch could lead to a greater sense of tonality, and hence an increased salience of the root, is also consistent with the doubling of the root in traditional four-part harmony. Accordingly, in Experiment 3, the same root position chords and second inversion chords from Experiment 2 were presented, and the root, third, and fifth of each of the first inversion chords from Experiment 2 were lowered by one octave. This modification ensured that the pitch of the root did not change across chord positions and that within each key two different pitches were needed to specify the third and two different pitches were needed to specify the fifth.

## METHOD

### Participants

Forty-eight undergraduates from the same pool used in Experiments 1 and 2 participated, and none of the listeners had participated in Experiment 1 or

2; 24 listeners participated in Experiment 3A, and 24 listeners participated in Experiment 3B.

### Apparatus

The apparatus was the same as in Experiment 1.

### Stimuli

The stimuli were the same as in Experiment 2, with the following exception: The frequencies of the root, third, and fifth components of each of the first inversion chords were lowered by one octave (see Figure 1, bottom). In Experiments 3A and 3B, each listener received 144 trials—three chord positions (root position, first inversion, second inversion)  $\times$  four targets (root, third, fifth, tritone)  $\times$  six root pitches (C, D, E, F $\sharp$ , G $\sharp$ , A $\sharp$ )  $\times$  two replications—in a different random order.

### Procedure

The procedure for Experiment 3A was the same as in Experiment 1A, and the procedure for Experiment 3B was the same as in Experiment 1B.

## RESULTS

Listeners in Experiments 3A and 3B were divided into musically experienced and musically inexperienced groups on the basis of a median split of scores on the musical background questionnaire. The probabilities of a “same” response in Experiments 3A and 3B were then analyzed in separate repeated-measures analyses of variance in which target and chord position were within-subject variables and experience was a between-subject variable.

### EXPERIMENT 3A

Listeners in the inexperienced group reported a mean of 0.33 year (range 0–2 years) of instrumental, voice, and music theory experience, and listeners in the experienced group reported a mean of 11.19 years (range 4–24 years) of instrumental, voice, and music theory experience. Experience was not significant, nor did experience interact with any other variables. Target was significant,  $F(3, 69) = 152$ ,  $MSE = 0.05$ ,  $p < .001$ , and a post-hoc Newman-Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between the root ( $M = .48$ ), third ( $M = .58$ ), fifth ( $M = .96$ ), and tritone ( $M = .22$ ) were significant except for the root versus third comparison. Target also interacted with chord position,  $F(6, 138) = 3.75$ ,  $MSE = 0.02$ ,  $p < .002$ . As shown in Table 3, chord position had a stronger influence on the recognition of the tritone than on the recognition of the root, third, or fifth.

Table 3. The probability of a "same" response in Experiments 3A and 3B

	Chord position		
	Root position	First inversion	Second inversion
Experiment 3A			
Root	.44	.51	.49
Third	.59	.58	.56
Fifth	.96	.95	.95
Tritone	.34	.15	.18
Experiment 3B			
Root	.68	.74	.75
Third	.75	.78	.84
Fifth	.91	.91	.96
Tritone	.15	.14	.17

### EXPERIMENT 3B

Listeners in the inexperienced group reported a mean of 0.15 years (range 0–1 years) of instrumental, voice, and music theory experience, and listeners in the experienced group reported a mean of 8.83 years (range 2–17 years) of instrumental, voice, and music theory experience. Experience was not significant, nor did it interact with any other variables. Target was significant,  $F(3, 69) = 126.58$ ,  $MSE = 0.07$ ,  $p < .001$ , and a post-hoc Newman–Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between the root ( $M = .73$ ), third ( $M = .79$ ), fifth ( $M = .92$ ), and tritone ( $M = .15$ ) were significant except for the root versus third comparison. Chord position was significant,  $F(2, 46) = 6.79$ ,  $MSE = 0.01$ ,  $p < .003$ , and a post-hoc Newman–Keuls test ( $p < .05$ ) revealed that all pairwise comparisons between root position ( $M = .62$ ), first inversion ( $M = .64$ ), and second inversion ( $M = .68$ ) chords were significant except for the root position versus first inversion comparison. The target  $\times$  chord position interaction did not approach significance.

### DISCUSSION

Consistent with Experiments 1 and 2, listeners in Experiment 3 exhibited a higher recognition rate for the fifth than for the root or the third; the higher recognition rate for the fifth in Experiments 3A and 3B occurred despite the more frequent presentation of a single pitch corresponding to the root within each key. It may be that the use of a single pitch as the root within each key did not induce a stronger activation of key; alternatively, the higher recognition for the fifth might

not have been influenced by changes in the strength of the activation of key that resulted from the use of a single pitch as the root within each key. Somewhat surprisingly, the probability of a "same" response to the tritone was influenced by chord position in Experiment 3A; the high percentage of "same" responses in Experiment 3A when the target was the tritone and the chord was in root position (34%) is not consistent with the idea that listeners experienced a stronger sense of tonality, because a stronger sense of tonality would be predicted to decrease the likelihood of a "same" response to the tritone.

## **GENERAL DISCUSSION**

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The current experiments did not find evidence consistent with root tracking or melody tracking. Listeners did not consistently exhibit the highest recognition rates for the root or for the highest-frequency component; rather, listeners consistently exhibited the highest recognition rate for the fifth. The consistently higher recognition rate of the fifth did not depend on repetition priming because this pattern occurred regardless of whether the construction of the different chord positions resulted in a single pitch being used for the root (Experiment 3), third (Experiment 2), or fifth (Experiment 1) in each key. The higher recognition rate for the fifth is consistent with previous findings that the fifth of a chord was judged as fitting a chord context better than did the third (Thompson & Parncutt, 1997) and with better discrimination for the top voice in a root position chord (DeWitt & Samuel, 1990). Indeed, given that the fifth is the highest voice in a root position chord, a higher recognition rate for the fifth may underlie apparent melody tracking in more traditional compositions in which a sequence of root position chords is presented.

One possible reason for the failure to obtain root tracking or melody tracking in Experiments 1, 2, and 3 is that the isolated single chords may not have offered sufficient context to evoke root tracking or melody tracking. It is possible that additional context (e.g., a cadence or sequence of diatonic chords) presented before the presentation of the chord and the target would more strongly activate or prime musical schema (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982), and it could be predicted that with such additional context root tracking or melody tracking would emerge. However, presentation of a single chord is sufficient for the production of harmonic priming (Bharucha & Stoeckig, 1986, 1987; Tekman & Bharucha, 1998), and major chords in isolation provide sufficient context to establish a tonal center (Krumhansl, Bharucha, & Kessler, 1982; Roberts & Shaw,

1984), so the major chords used in Experiments 1, 2, and 3 presumably should have produced a sufficient amount of musical context to evoke musical schemata. Rather than reflecting a lack of schematic activation, the lack of root tracking or melody tracking in Experiments 1, 2, and 3 might reflect the lack of any changes during the presentation of a single chord; the idea of tracking a specific component of a chord implies a movement of pitch, and in the absence of movement, the notion of tracking loses clear meaning.

A second possible reason for the failure to obtain root tracking or melody tracking involves the instructional set given to listeners. In Experiments 1, 2, and 3, listeners were given an "analytic set" that would have encouraged the hearing of individual component tones of the chord. In Platt and Racine's (1990) study, listeners were given a more "synthetic set" in which they were encouraged to judge which component tone sounded the most similar to the entire chord. In Experiments 1, 2, and 3 and in Platt and Racine's studies, listeners were presented in each trial with a major chord and a single pitch, but listeners in Experiments 1, 2, and 3 did not exhibit root tracking or melody tracking, whereas listeners in Platt and Racine's studies did exhibit root tracking or melody tracking. It could be that a synthetic set focuses more on the entire chord and thus increases sensitivity to implied musical context. An analytic set focuses on the individual notes and thus diminishes sensitivity to the implied musical context, so recognition of the individual notes is not facilitated by musical context. Similarly, participants in harmonic priming studies often judged whether the target was in tune or out of tune or whether the target was major or minor, and both types of judgments involve the relationship between components of the chord and thus may involve a more synthetic set.

A third possible reason for the failure to obtain root tracking or melody tracking involves differences in the extent to which a musical context had been instantiated. Platt and Racine (1990) presented stimuli drawn from only a single key (A major), and this would have strongly instantiated and maintained a single key context throughout the experiment. Indeed, Platt and Racine noted that many of their musically trained participants identified and commented on the continual use of A major chords. Experiments 1, 2, and 3 presented stimuli drawn from six different root pitches that varied randomly across trials. This would not have instantiated and maintained a single key context, so the musical or tonal context would have been much weaker in Experiments 1, 2, and 3 than in Platt and Racine's studies. This is consistent with the possibility that the stimuli in Experiments 1, 2, and 3 did not offer sufficient musical context to evoke root tracking or melody tracking schemata and is also consistent with DeWitt and Samuel's (1990) find-

ing that observers may exhibit different biases for the voices of a chord as a function of whether that chord is presented in or out of a musical context. Along these lines, it is possible that the use of sine wave stimuli reduced musical context by removing a highly salient source of harmonic information.

A more positive reason for the apparent failure to obtain root tracking or melody tracking and for the greater recognition of the fifth might relate to the role of the fifth in voice leading and harmonic progression. The circle-of-fifths progression is a harmonic pattern that often appears in connection with melodic sequences, as a tonic triad is often preceded by a chord based on the fifth (Kostka & Payne, 1995). Indeed, the root and the fifth are so critical to harmony that Schenker (1954) suggested that any tonal composition can be understood as an elaborated I V I harmonic progression, and Rosner and Narmour (1992) found that cadences involving a V I progression produced a greater sense of closure than cadences involving other progressions. In a more extended musical composition, it is possible that a greater recognition of the fifth might aid perception of the subsequent harmonic progression. Similarly, exposure to tonal music may have shaped musical schemata to exhibit such a greater sensitivity, so the greater recognition of the fifth may reflect some sort of priming or expectation of subsequent harmony. The greater sensitivity to the fifth might also indicate that listeners harmonically (but not melodically) hear intervals that are larger than a fifth as inversions of smaller intervals at the octave (e.g., hear a sixth and a seventh as a third and a second, respectively; see Balzano & Liesch, 1982); in other words, listeners may be more sensitive to the fifth because it is the largest functional simultaneous interval that they perceive.

The lack of a significant chord position effect in Experiments 1A, 2A, 3A, 1B, and 2B suggests that chord position did not in general influence how well listeners could recognize each of the component tones of the major chords. This pattern is consistent with previous reports that chord position generally does not influence the magnitude of harmonic priming (Stoeckig, 1990) and with music theoretic claims of the harmonic equivalence of different chord positions. The significant chord position main effect in Experiment 3B, coupled with the significant target  $\times$  chord position interaction in all the experiments except for Experiment 3B, suggests that chord position did have subtle and specific effects on the recognition of tones and that chord positions may not be harmonically equivalent in all aspects. Suggestively, chord position had an effect only when the root was emphasized (in Experiment 3B), suggesting that the importance of the root may be a function of the strength of the musical context. A more complete explanation of the slight dif-

ferences in recognition rates for tones across chord positions awaits future investigation.

Listeners were less accurate at recognizing whether a currently perceived tone had been contained within a previously perceived chord (Experiments 1A, 2A, and 3A) than at recognizing whether a currently perceived chord contained a previously perceived tone (Experiments 1B, 2B, and 3B). If we consider chords as background and single tones (as melody) as figure, then this difference may reflect a fundamental asymmetry in processing such that it is more difficult to judge whether the background contains an element of the figure than to judge whether the figure contains an element of the background. Such a hypothesis would parallel findings in the visual perception literature in which detection of a stimulus is facilitated if that stimulus appears against a figure rather than against a background (Wong & Weisstein, 1982). Alternatively, this difference in recognition rates may result from a difference in the relative memory loads; in Experiments 1A, 2A, and 3A listeners maintained a chord in memory, whereas in Experiments 1B, 2B, and 3B listeners maintained a single tone in memory. A related possibility is that the differences may result from an asymmetry in attentional demand: When the target is presented first, the listener can focus on the corresponding pitch height when the chord is presented, whereas when the chord is presented first, the "search space" within pitch representation is much larger.

Perhaps even more surprising than the higher recognition rate of the fifth was the finding that the recognition rates of the root and the third were close to chance in Experiments 1A, 2A, and 3A. Given the two options for response, "same" or "different," chance performance would have been at 50%. When the chord was presented before the target, listeners appeared unable to recognize either the root or the third, but they were able to recognize the fifth and correctly reject the tritone. Indeed, the lack of recognition of the root and the third is even more striking in light of a consideration that a "same" bias in responding was favored by having three targets that were contained in the chord and only one target that was not contained in the chord. The recognition rates of the root and the third were much higher in Experiments 1B, 2B, and 3B. When the target was presented before the chord, listeners were more able to recognize the root and the third, although recognition of the root and third was still below that of the fifth and the tritone. This improvement may simply result from differences in memory loads or attentional demands.

The primary empirical finding was that listeners were more accurate at recognizing the fifth of a major chord than at recognizing the root or the third of a major chord, and this general pattern occurred regard-

less of whether the chord was presented in root position, first inversion, or second inversion and regardless of the specific auditory frequencies involved. This pattern is not consistent with narrow conceptions of melody tracking or root tracking, although a consideration of the principles of voice leading may suggest a way in which a higher recognition rate of the fifth might aid in perceiving a subsequent tonal progression. This pattern is consistent with the importance of the fifth in harmonic progression and with evidence suggesting that larger intervals may be heard as smaller inverted intervals. Given the higher recognition rate of the fifth across all the experiments and the notion that chords based on the fifth are called dominant chords in music theory, we might suggest that in addition to engaging in root tracking and melody tracking, listeners may also engage in dominant tracking. Such a notion is highly speculative at this point, but it is clear that not all components of a major chord are recognized equally well.

## Appendix

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A chord consists of two or more notes sounded simultaneously. Typically, when the frequencies of the notes are in a simple integer ratio to each other (e.g., 2:1, 3:2, 4:3), the combination is considered consonant. A tuning of chords and intervals based solely on integer ratios breaks down, however, when one tries to compare intervals in different scales and keys, so contemporary Western tonal music is based on an equal-tempered tuning in which the octave is defined as a 2:1 ratio (e.g., middle C is 261.63 Hz, and the C an octave above middle C is therefore  $261.63 \times 2 = 523.25$  Hz), and the octave is divided into 12 logarithmically equally spaced notes (e.g., if middle C is 261.63 Hz, then C $\sharp$  is  $261.63 \times 2^{1/12} = 277.18$  Hz, D is  $261.63 \times 2^{2/12} = 293.66$  Hz). The major third and the fifth of a major chord correspond to the fourth and seventh notes in this chromatic scale. Therefore, in a C major scale, the major third would be E ( $261.63 \times 2^{4/12} = 329.63$  Hz), the fifth would be G ( $261.63 \times 2^{7/12} = 392.00$  Hz). In a major scale, only 7 of the 12 chromatic steps are included, and one of the steps that is not included is the sixth, and this note is called the tritone. For C, the tritone is F $\sharp$  ( $261.63 \times 2^{6/12} = 369.99$  Hz). Similar formulas can be used to calculate pitches a major third (root frequency  $\times 2^{4/12}$ ), fifth (root frequency  $\times 2^{7/12}$ ), or tritone (root frequency  $\times 2^{6/12}$ ) from any root frequency. The different chromatic steps, and which elements are included within a major scale, are listed in Table A1. More details on chord construction can be found in Pierce (1992) and Burns (1999).

The method just outlined would produce a major chord in which the root was the lowest pitch, the third was intermediate to the root and the fifth, and the fifth was the highest pitch. However, this ordering of pitches need not always be used. As long as tone chroma are preserved, that is, as long as tones with the same letter names are used, tones can be drawn from any octave. When

Table A1. The elements of a chromatic and major scale (equal-tempered tuning) in the key of C.

		Letter name	Frequency ratio	Step size
Root/unison <sup>a</sup>	DO	C	1.000	$2^{(0/12)}$
Minor second		C#	1.059	$2^{(1/12)}$
Major second <sup>a</sup>	RE	D	1.122	$2^{(2/12)}$
Minor third		D#	1.189	$2^{(3/12)}$
Major third <sup>a</sup>	MI	E	1.260	$2^{(4/12)}$
Fourth <sup>a</sup>	FA	F	1.335	$2^{(5/12)}$
Tritone		F#	1.414	$2^{(6/12)}$
Fifth <sup>a</sup>	SO	G	1.498	$2^{(7/12)}$
Minor sixth		G#	1.587	$2^{(8/12)}$
Major sixth <sup>a</sup>	LA	A	1.682	$2^{(9/12)}$
Minor seventh		A#	1.782	$2^{(10/12)}$
Major seventh <sup>a</sup>	TI	B	1.833	$2^{(11/12)}$
Octave <sup>a</sup>	DO	C	2.000	$2^{(12/12)}$

<sup>a</sup>Notes in a major scale.

the root is the lowest pitch, such a chord is said to be in root position. The root can be raised an octave or the third can be dropped an octave, and when the third is the lowest note, the chord is said to be in first inversion. If the root and third are raised or if the fifth is dropped an octave, the chord is said to be in second inversion. The creation of different chord positions by successive raising of the root and then the third by an octave is illustrated in Figure A1. The different chord positions often are considered to be harmonically equivalent in music theory. More details on chord inversions can be found in Kostka and Payne (1995), Piston (1978), and Williams (1992).



Root Position      First Inversion      Second Inversion

Figure A1. Examples of root position, first inversion, and second inversion chords in the key of C major; arrows indicate which pitches are moved to create each inversion

## Notes

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